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APPENDIX TO HYDROLOGICAL MEMORANDA N° 33

(issued with first reprint in August 1968)

Tables of rainfall amounts and intensities for given durations and return periods together with area factor graphs

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APPENDIX TO HYDROLOGICAL MEMORANDA NO 33

Since Memorandum No 33 was written, many of its practical implications have been worked out and it has been thought useful to publish these as an appendix. Eventually a separate Memorandum dealing with rainfall data for drainage design will be produced. For convenience, the Memorandum will be considered section by section.

I. Bilham treatment

No further comment is necessary.

II. Later developments

Two basic recommendations were made. The first was to amend the constant in Bilham's formula to 1.39 (i.e. 1.25 x 10/9). This change is considered too small compared with the variations between stations to justify the amendment of the tables at this stage.

The second was the straightening-off of the curve as the origin ($r = 0$, $t = 0$) was approached. This makes no difference to tabulations for times $\geq$ 1 minute and for return periods $\geq$ 1 year and has therefore been ignored.

III. Gumbel treatment

The development of the ideas discussed in this section leads to the replacement of Bilham's formula for intensities greater than 1.25 inches per hour by the following formula:

$$n = \frac{r \exp\left(1 - \frac{0.8r}{t}\right)}{(r + 0.1)^{3.55}}$$

where n, r and t have the same meanings as in Bilham's formula. The coloured "rain intensity frequency graphs" in Hydrological Memoranda No 33 illustrate the need for this modification. However, the above equation is difficult to solve for r and it is necessary to tabulate r as a function of t and n. Tables I to IV have been produced from solutions obtained by Road Research Laboratory on their computer.

/IV.

IV. Regional variations

Work in this field is continuing. As records accumulate it is becoming increasingly possible to analyse local tabulations (Forms 3441) and produce modified tables such as Table V. As the format is slightly different from that used in the main tables, Table IV has been reproduced in the shorter format (Table VI) for comparison with the local values (Table V). The cost of supplying such tables varies slightly, but usually is between £10 and £15.

V. Area effect

Holland (1967) has proposed a formula for estimating the smoothing effect of area. One way of expressing his formula is:

$$\Gamma\left(\frac{\sqrt{kA}}{1-F}\right) = t$$

where Γ denotes the gamma function

F is the reduction factor

A is the area

t is the time of concentration in minutes

k = 0.00036 if area is given in acres

or 0.0009 if area is given in hectares

The formula is valid for areas which are roughly circular and which are more or less evenly drained. The application of this formula to elongated or unevenly drained areas requires careful consideration. The formula is not easy to solve and so graphs (Figures 1 and 2) have been prepared to assist users in the calculation of the area factor. This factor can then be applied to any of the values obtained from Tables I to V to obtain the appropriate rainfall and intensity for the area under consideration.

Reference

D. J. Holland (1967) "The Cardington Rainfall Experiment"
Meteorological Magazine Vol 96. pp. 193-202
(July 1967)

Time (mins)	Return Period (years)						
	1	2	5	10	20	50	100
2	2.72	3.38	4.24	4.90	5.57	6.46	7.15
2½	2.57	3.18	4.01	4.64	5.28	6.14	6.81
3	2.43	3.01	3.80	4.41	5.03	5.87	6.52
3½	2.30	2.86	3.62	4.21	4.81	5.63	6.26
4	2.19	2.73	3.46	4.03	4.62	5.42	6.04
4½	2.09	2.61	3.32	3.88	4.45	5.23	5.85
5	2.00	2.50	3.19	3.73	4.30	5.07	5.67
5½	1.92	2.40	3.07	3.61	4.16	4.91	5.51
6	1.84	2.31	2.97	3.49	4.03	4.77	5.36
7	1.71	2.15	2.78	3.28	3.80	4.53	5.10
8	1.60	2.02	2.62	3.10	3.61	4.31	4.87
9	1.50	1.90	2.48	2.95	3.44	4.13	4.67
10	1.41	1.80	2.36	2.81	3.29	3.96	4.49
11	1.34	1.71	2.25	2.69	3.15	3.81	4.33
12	1.27	1.63	2.15	2.58	3.03	3.68	4.19
13	1.21	1.55	2.06	2.48	2.92	3.55	4.06
14	1.15	1.49	1.98	2.38	2.82	3.44	3.94
15	1.11	1.43	1.90	2.30	2.73	3.34	3.83
16	1.06	1.37	1.84	2.22	2.64	3.24	3.72
17	1.02	1.32	1.77	2.15	2.56	3.15	3.63
18	0.99	1.27	1.71	2.09	2.49	3.07	3.54
19	0.96	1.23	1.66	2.02	2.42	2.99	3.45
20	0.93	1.19	1.61	1.97	2.36	2.92	3.37
25	0.80	1.03	1.40	1.72	2.08	2.61	3.04
30	0.72	0.91	1.24	1.54	1.87	2.37	2.78
35	0.65	0.83	1.12	1.39	1.71	2.17	2.56
40	0.59	0.76	1.02	1.27	1.57	2.01	2.38
45	0.55	0.70	0.94	1.18	1.45	1.87	2.23
50	0.51	0.65	0.88	1.09	1.35	1.76	2.10
55	0.48	0.61	0.82	1.02	1.27	1.65	1.98
60	0.46	0.58	0.78	0.96	1.19	1.56	1.88
70	0.41	0.52	0.70	0.87	1.07	1.41	1.71
80	0.38	0.48	0.64	0.79	0.98	1.29	1.57
90	0.35	0.44	0.59	0.73	0.90	1.19	1.45
100	0.33	0.41	0.55	0.68	0.84	1.10	1.35
110	0.31	0.38	0.51	0.63	0.78	1.03	1.26
2 hrs	0.29	0.36	0.48	0.60	0.74	0.97	1.19
3 hrs	0.22	0.27	0.36	0.45	0.55	0.73	0.89
4 hrs	0.18	0.22	0.30	0.37	0.45	0.59	0.73
5 hrs	0.16	0.19	0.26	0.32	0.39	0.51	0.62
6 hrs	0.14	0.17	0.23	0.28	0.34	0.45	0.55
7 hrs	0.12	0.15	0.20	0.25	0.31	0.40	0.49
8 hrs	0.11	0.14	0.18	0.23	0.28	0.36	0.44
9 hrs	0,10	0.13	0.17	0.21	0.26	0.33	0.41
10 hrs	0.10	0.12	0.16	0.19	0.24	0.31	0.38
11 hrs	0.09	0.11	0.15	0.18	0.22	0.29	0.35
12 hrs	0.09	0.11	0.14	0.17	0.21	0.27	0.33
18 hrs	0.06	0.08	0.10	0.13	0.16	0.20	0.25
24 hrs	0.05	0.06	0.09	0.10	0.13	0.17	0.20

Table I. The variation of rate of rainfall in inches per hour with duration and return period

Time (mins)	Return Period (years)						
	1	2	5	10	20	50	100
2	69.2	85.8	107.8	124.6	141.5	164.2	181.5
2½	65.2	80.9	101.8	117.8	134.1	156.0	172.9
3	61.6	76.5	96.5	112.0	127.8	149.1	165.5
3½	58.5	72.7	91.9	106.9	122.3	143.0	159.1
4	55.6	69.3	87.9	102.4	117.4	137.7	153.5
4½	53.1	66.2	84.3	98.4	113.1	133.0	148.5
5	50.8	63.5	81.0	94.9	109.1	128.7	143.9
5½	48.7	61.0	78.1	91.6	105.6	124.8	139.8
6	46.8	58.7	75.4	88.6	102.4	121.3	136.1
7	43.4	54.7	70.6	83.3	96.6	115.0	129.4
8	40.5	51.3	66.5	78.8	91.7	109.6	123.7
9	38.0	48.3	63.0	74.9	87.4	104.8	118.6
10	35.9	45.7	59.8	71.4	83.5	100.6	114.1
11	33.9	43.4	57.1	68.2	80.1	96.8	110.1
12	32.2	41.3	54.6	65.4	77.0	93.4	106.4
13	30.7	39.5	52.3	62.9	74.2	90.3	103.1
14	29.3	37.8	50.2	60.6	71.7	87.4	100.0
15	28.1	36.2	48.4	58.4	69.3	84.8	97.2
16	27.0	34.8	46.6	56.5	67.1	82.3	94.6
17	26.0	33.5	45.0	54.7	65.1	80.1	92.2
18	25.1	32.3	43.5	53.0	63.2	77.9	89.9
19	24.3	31.2	42.2	51.4	61.5	76.0	87.7
20	23.5	30.2	40.9	49.9	59.8	74.1	85.7
25	20.4	26.1	35.6	43.8	52.9	66.2	77.2
30	18.2	23.2	31.5	39.1	47.6	60.1	70.5
35	16.5	21.0	28.4	35.4	43.3	55.2	65.1
40	15.1	19.2	26.0	32.4	39.8	51.0	60.5
45	14.0	17.7	24.0	29.9	36.9	47.6	56.7
50	13.1	16.5	22.3	27.8	34.4	44.6	53.3
55	12.3	15.5	20.9	26.0	32.2	42.0	50.4
60	11.6	14.6	19.7	24.5	30.3	39.7	47.8
70	10.5	13.2	17.7	22.0	27.3	35.8	43.4
80	9.6	12.1	16.2	20.1	24.8	32.7	39.8
90	8.9	11.2	14.9	18.5	22.9	30.1	36.8
100	8.3	10.4	13.9	17.2	21.3	28.0	34.3
110	7.8	9.7	13.0	16.1	19.9	26.2	32.1
2 hrs	7.3	9.2	12.3	15.2	18.7	24.6	30.2
3 hrs	5.6	7.0	9.3	11.4	14.1	18.5	22.7
4 hrs	4.6	5.7	7.6	9.4	11.5	15.1	18.5
5 hrs	3.9	4.9	6.5	8.0	9.8	12.9	15.8
6 hrs	3.5	4.3	5.7	7.0	8.7	11.3	13.9
7 hrs	3.1	3.9	5.1	6.3	7.8	10.2	12.4
8 hrs	2.9	3.5	4.7	5.8	7.1	9.2	11.3
9 hrs	2.6	3.3	4.3	5.3	6.5	8.5	10.4
10 hrs	2.5	3.0	4.0	4.9	6.0	7.9	9.6
11 hrs	2.3	2.8	3.7	4.6	5.6	7.4	9.0
12 hrs	2.2	2.7	3.5	4.3	5.3	6.9	8.5
18 hrs	1.6	2.0	2.7	3.3	4.0	5.2	6.3
24 hrs	1.3	1.7	2.2	2.7	3.3	4.2	5.2

Table II. The variation of rate of rainfall in millimetres per hour with duration and return period

Time (mins)	Return Period (years)						
	1	2	5	10	20	50	100
2	0.09	0.11	0.14	0.16	0.19	0.22	0.24
2½	0.11	0.13	0.17	0.19	0.22	0.26	0.28
3	0.12	0.15	0.19	0.22	0.25	0.29	0.33
3½	0.13	0.17	0.21	0.25	0.28	0.33	0.37
4	0.15	0.18	0.23	0.27	0.31	0.36	0.40
4½	0.16	0.20	0.25	0.29	0.33	0.39	0.44
5	0.17	0.21	0.27	0.31	0.36	0.42	0.47
5½	0.18	0.22	0.28	0.33	0.38	0.45	0.50
6	0.18	0.23	0.30	0.35	0.40	0.48	0.54
7	0.20	0.25	0.32	0.38	0.44	0.53	0.59
8	0.21	0.27	0.35	0.41	0.48	0.58	0.65
9	0.22	0.29	0.37	0.44	0.52	0.62	0.70
10	0.24	0.30	0.39	0.47	0.55	0.66	0.75
11	0.24	0.31	0.41	0.49	0.58	0.70	0.79
12	0.25	0.33	0.43	0.52	0.61	0.74	0.84
13	0.26	0.34	0.45	0.54	0.63	0.77	0.88
14	0.27	0.35	0.46	0.56	0.66	0.80	0.92
15	0.28	0.36	0.48	0.58	0.68	0.83	0.96
16	0.28	0.37	0.49	0.59	0.70	0.86	0.99
17	0.29	0.37	0.50	0.61	0.73	0.89	1.03
18	0.30	0.38	0.51	0.63	0.75	0.92	1.06
19	0.30	0.39	0.53	0.64	0.77	0.95	1.09
20	0.31	0.40	0.54	0.66	0.79	0.97	1.12
25	0.34	0.43	0.58	0.72	0.87	1.09	1.27
30	0.36	0.46	0.62	0.77	0.94	1.18	1.39
35	0.38	0.48	0.65	0.81	1.00	1.27	1.49
40	0.40	0.50	0.68	0.85	1.05	1.34	1.59
45	0.41	0.52	0.71	0.88	1.09	1.40	1.67
50	0.43	0.54	0.73	0.91	1.13	1.46	1.75
55	0.44	0.56	0.75	0.94	1.16	1.52	1.82
60	0.46	0.58	0.78	0.96	1.19	1.56	1.88
70	0.48	0.61	0.81	1.01	1.25	1.65	1.99
80	0.50	0.63	0.85	1.05	1.30	1.72	2.09
90	0.52	0.66	0.88	1.09	1.35	1.78	2.18
100	0.54	0.68	0.91	1.13	1.39	1.84	2.25
110	0.56	0.70	0.94	1.16	1.44	1.89	2.32
2 hrs	0.58	0.72	0.96	1.19	1.47	1.94	2.38
3 hrs	0.66	0.82	1.09	1.35	1.66	2.18	2.68
4 hrs	0.72	0.90	1.19	1.47	1.81	2.38	2.91
5 hrs	0.78	0.96	1.28	1.58	1.94	2.54	3.11
6 hrs	0.82	1.02	1.35	1.66	2.04	2.68	3.27
7 hrs	0.86	1.07	1.42	1.74	2.14	2.80	3.42
8 hrs	0.90	1.12	1.47	1.81	2.23	2.91	3.56
9 hrs	0.93	1.16	1.53	1.88	2.30	3.01	3.68
10 hrs	0.96	1.19	1.58	1.94	2.38	3.11	3.80
11 hrs	0.99	1.23	1.62	1.99	2.44	3.19	3.90
12 hrs	1.02	1.26	1.66	2.04	2.51	3.27	4.00
18 hrs	1.16	1.43	1.88	2.30	2.82	3.68	4.50
24 hrs	1.26	1.56	2.04	2.51	3.07	4.00	4.89

Table III The variation of quantity of rainfall in inches with duration and return period

Time (mins)	Return Period (years)						
	1	2	5	10	20	50	100
2	2.3	2.9	3.6	4.2	4.7	5.5	6.1
2½	2.7	3.4	4.2	4.9	5.6	6.5	7.2
3	3.1	3.8	4.8	5.6	6.4	7.5	8.3
3½	3.4	4.2	5.4	6.2	7.1	8.3	9.3
4	3.7	4.6	5.9	6.8	7.8	9.2	10.2
4½	4.0	5.0	6.3	7.4	8.5	10.0	11.1
5	4.2	5.3	6.8	7.9	9.1	10.7	12.0
5½	4.5	5.6	7.2	8.4	9.7	11.4	12.8
6	4.7	5.9	7.5	8.9	10.2	12.1	13.6
7	5.1	6.4	8.2	9.7	11.3	13.4	15.1
8	5.4	6.8	8.9	10.5	12.2	14.6	16.5
9	5.7	7.2	9.4	11.2	13.1	15.7	17.8
10	6.0	7.6	10.0	11.9	13.9	16.8	19.0
11	6.2	8.0	10.5	12.5	14.7	17.7	20.2
12	6.4	8.3	10.9	13.1	15.4	18.7	21.3
13	6.7	8.6	11.3	13.6	16.1	19.6	22.3
14	6.8	8.8	11.7	14.1	16.7	20.4	23.3
15	7.0	9.1	12.1	14.6	17.3	21.2	24.3
16	7.2	9.3	12.4	15.1	17.9	22.0	25.2
17	7.4	9.5	12.8	15.5	18.4	22.7	26.1
18	7.5	9.7	13.1	15.9	19.0	23.4	27.0
19	7.7	9.9	13.4	16.3	19.5	24.1	27.8
20	7.8	10.1	13.6	16.6	19.9	24.7	28.6
25	8.5	10.9	14.8	18.3	22.0	27.6	32.2
30	9.1	11.6	15.8	19.6	23.8	30.0	35.2
35	9.6	12.2	16.6	20.7	25.3	32.2	37.9
40	10.1	12.8	17.3	21.6	26.6	34.0	40.3
45	10.5	13.3	18.0	22.4	27.7	35.7	42.5
50	10.9	13.8	18.6	23.2	28.7	37.2	44.4
55	11.3	14.2	19.2	23.9	29.5	38.5	46.2
60	11.6	14.6	19.7	24.5	30.3	39.7	47.8
70	12.2	15.4	20.7	25.7	31.8	41.8	50.7
80	12.8	16.1	21.6	26.8	33.1	43.6	53.1
90	13.3	16.7	22.4	27.8	34.3	45.2	55.3
100	13.8	17.3	23.2	28.7	35.4	46.6	57.2
110	14.2	17.8	23.9	29.5	36.5	47.9	58.8
2 hrs	14.6	18.4	24.5	30.3	37.4	49.2	60.4
3 hrs	16.7	20.9	27.8	34.3	42.3	55.5	68.0
4 hrs	18.4	22.9	30.3	37.4	46.0	60.4	73.9
5 hrs	19.7	24.5	32.5	40.0	49.2	64.4	78.9
6 hrs	20.9	25.9	34.3	42.3	51.9	68.0	83.2
7 hrs	21.9	27.2	36.0	44.3	54.3	71.1	87.0
8 hrs	22.9	28.3	37.4	46.0	56.5	73.9	90.4
9 hrs	23.7	29.4	38.8	47.7	58.5	76.5	93.5
10 hrs	24.5	30.3	40.0	49.2	60.4	78.9	96.4
11 hrs	25.2	31.2	41.2	50.6	62.1	81.1	99.1
12 hrs	25.9	32.1	42.3	51.9	63.7	83.2	101.7
18 hrs	29.4	36.3	47.7	58.5	71.7	93.5	114.3
24 hrs	32.1	39.5	51.9	63.7	77.9	101.7	124.1

Table IV The variation of quantity of rainfall in millimetres with duration and return period

Duration (mins)	Return period (years) 1		2		5		10		20		50		100
	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	
2	2.3	(0.09)	2.8	(0.11)	3.6	(0.14)	4.1	(0.16)	4.8	(0.19)	5.6	(0.22)	-
4	3.6	(0.14)	4.3	(0.17)	5.6	(0.22)	6.6	(0.26)	7.9	(0.31)	9.1	(0.36)	-
6	4.1	(0.16)	5.3	(0.21)	7.1	(0.28)	8.4	(0.33)	9.7	(0.38)	11.7	(0.46)	-
8	4.6	(0.18)	6.1	(0.24)	7.9	(0.31)	9.4	(0.37)	11.7	(0.44)	13.7	(0.54)	-
10	5.1	(0.20)	6.6	(0.26)	8.6	(0.34)	10.7	(0.42)	12.7	(0.50)	15.0	(0.59)	-
15	5.6	(0.22)	7.6	(0.30)	10.2	(0.40)	12.5	(0.49)	14.7	(0.58)	18.5	(0.73)	-
20	6.1	(0.24)	8.1	(0.32)	11.2	(0.44)	14.0	(0.55)	16.8	(0.66)	21.6	(0.85)	-
30	6.9	(0.27)	9.1	(0.36)	12.5	(0.49)	15.5	(0.61)	19.1	(0.75)	26.7	(1.05)	-
60	8.1	(0.32)	10.7	(0.42)	14.5	(0.57)	17.8	(0.70)	24.1	(0.95)	35.6	(1.40)	-
120	9.7	(0.38)	12.4	(0.49)	17.8	(0.70)	25.4	(1.00)	32.8	(1.29)	45.2	(1.78)	-
180		-		-		-		-		-		-	-
240		-		-		-		-		-		-	-
480		-		-		-		-		-		-	-

These data are based on tabulations from Renfrew over the period 1925 to 1935.
and from Abbottsinch over the period 1936 to 1945.
and from Renfrew over the period 1946 to 1965.

Short period data for durations less than 15 minutes are based only on records starting in 1956 or later.

[redacted]

Omitted values indicate that data currently analysed are inadequate to produce a useful estimate.

Table V Rainfall amounts in millimetres and inches

Revised Bilham formula

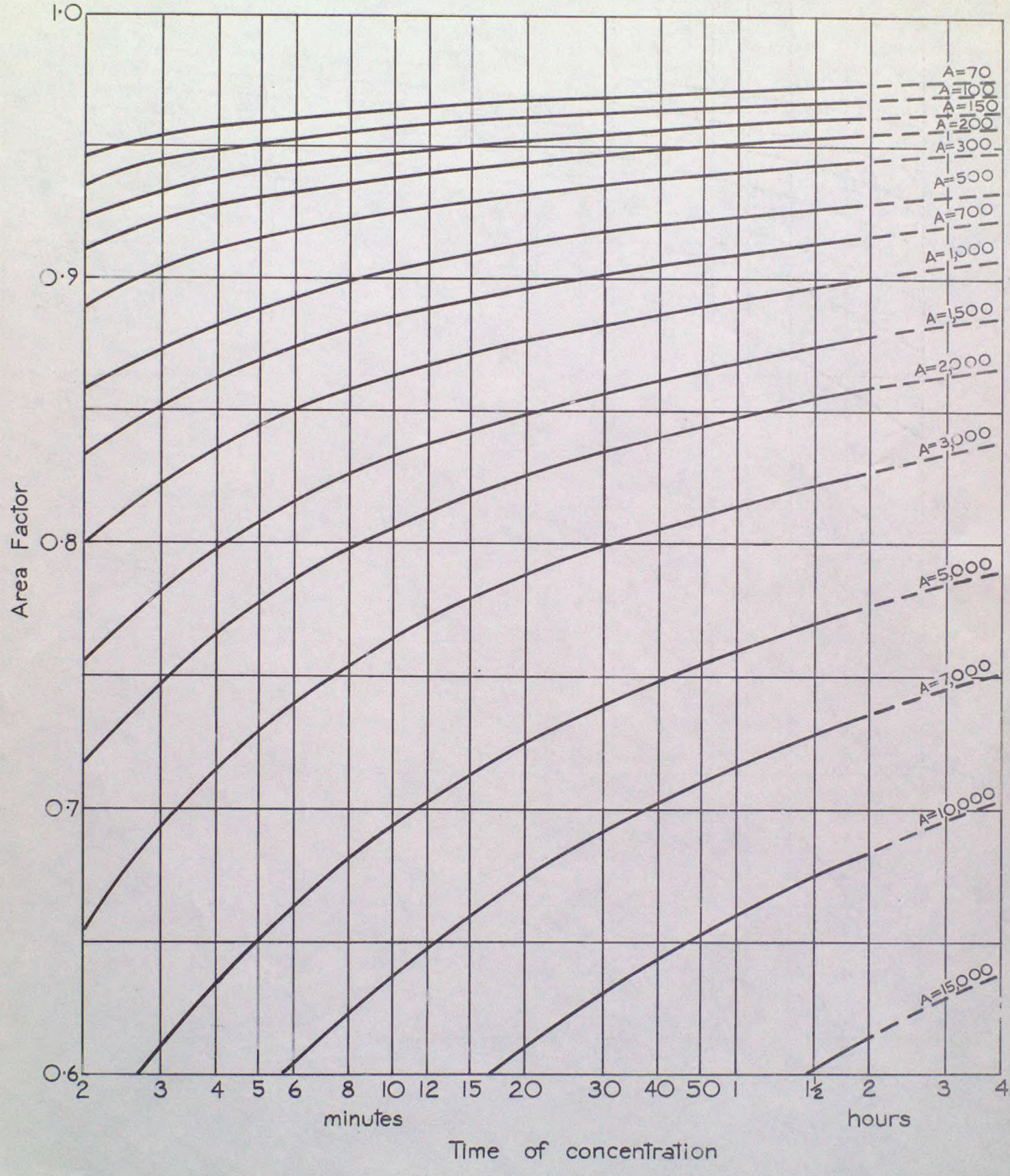
Duration (mins)	Return period (years) 1		2		5		10		20		50		100	
	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in
2	2.3	(0.09)	2.9	(0.11)	3.6	(0.14)	4.2	(0.16)	4.7	(0.19)	5.5	(0.22)	6.1	(0.24)
4	3.7	(0.15)	4.6	(0.18)	5.9	(0.23)	6.8	(0.27)	7.8	(0.31)	9.2	(0.36)	10.2	(0.40)
6	4.7	(0.18)	5.9	(0.23)	7.5	(0.30)	8.9	(0.35)	10.2	(0.40)	12.1	(0.48)	13.6	(0.54)
8	5.4	(0.21)	6.8	(0.27)	8.9	(0.35)	10.5	(0.41)	12.2	(0.48)	14.6	(0.58)	16.5	(0.65)
10	6.0	(0.24)	7.6	(0.30)	10.0	(0.39)	11.9	(0.47)	13.9	(0.55)	16.8	(0.66)	19.0	(0.75)
15	7.0	(0.28)	9.1	(0.36)	12.1	(0.48)	14.6	(0.58)	17.3	(0.68)	21.2	(0.83)	24.3	(0.96)
20	7.8	(0.31)	10.1	(0.40)	13.6	(0.54)	16.6	(0.66)	19.9	(0.79)	24.7	(0.97)	28.6	(1.12)
30	9.1	(0.36)	11.6	(0.46)	15.8	(0.62)	19.6	(0.77)	23.8	(0.94)	30.0	(1.18)	35.2	(1.39)
60	11.6	(0.46)	14.6	(0.58)	19.7	(0.78)	24.5	(0.96)	30.3	(1.19)	39.7	(1.56)	47.8	(1.88)
120	14.6	(0.58)	18.4	(0.72)	24.5	(0.96)	30.3	(1.19)	37.4	(1.47)	49.2	(1.94)	60.4	(2.38)
180	16.7	(0.66)	20.9	(0.82)	27.8	(1.09)	34.3	(1.35)	42.3	(1.66)	55.5	(2.18)	68.0	(2.68)
240	18.4	(0.72)	22.9	(0.90)	30.3	(1.19)	37.4	(1.47)	46.0	(1.81)	60.4	(2.38)	73.9	(2.91)
480	22.9	(0.90)	28.3	(1.12)	37.4	(1.47)	46.0	(1.81)	56.5	(2.23)	73.9	(2.91)	90.4	(3.56)

These data are based on tabulations from 10 stations over the period 1926 to 1960.

Short period data for durations less than 15 minutes are based only on records starting in 1956 or later.

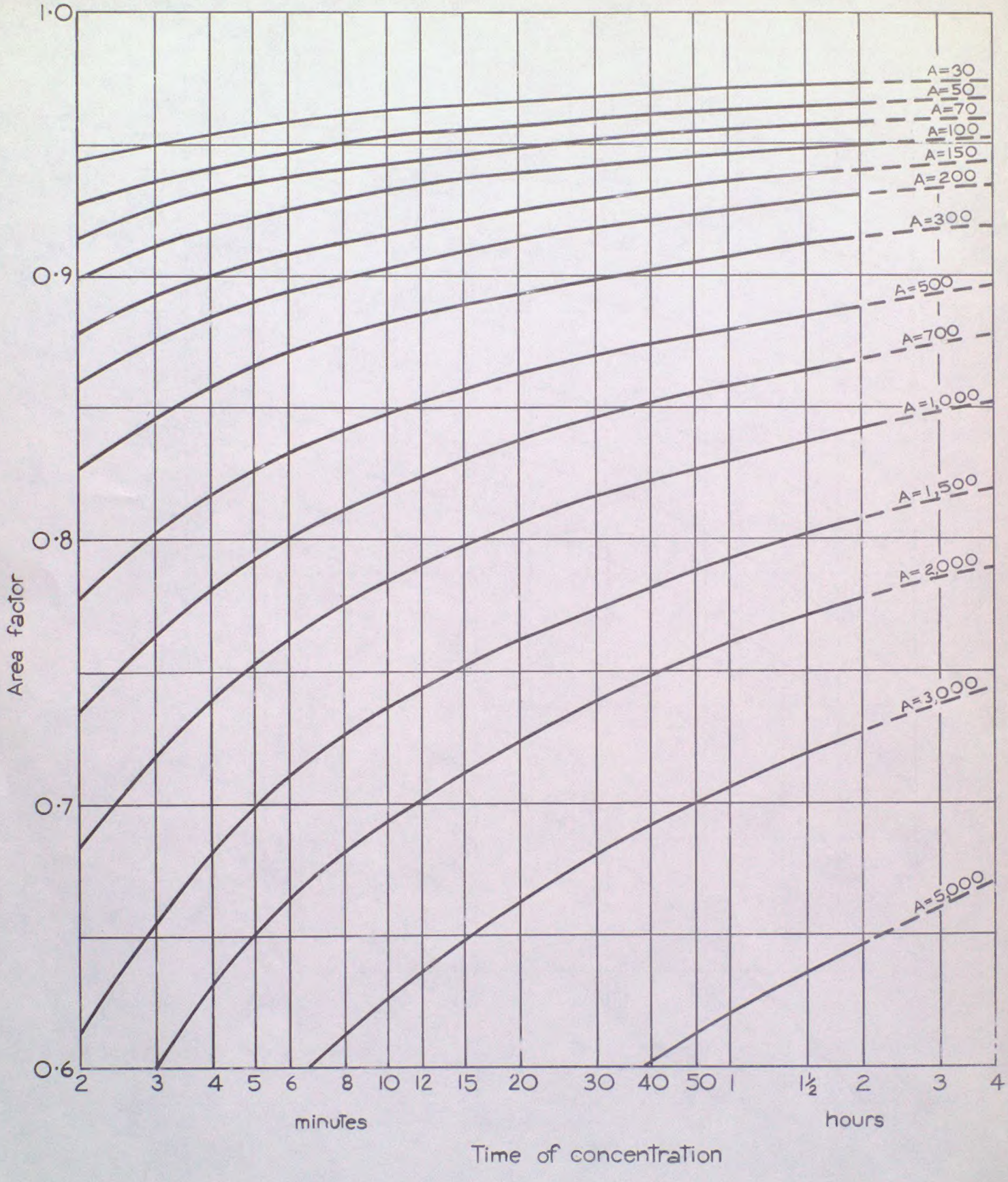
[redacted]

Table VI Rainfall amounts in millimetres and inches



Factors to be applied to estimated point rainfalls to obtain equivalent areal rainfalls Areas (A) between 70 and 15,000 acres based on Holland's formula $\Gamma\left(\frac{\sqrt{0{\cdot}00036A}}{1-F}\right)=t$ where F = area factor, A = area (acres) and t = time (minutes

Figure 1. Area factors. (Areas in acres).



Factors to be applied to estimated point rainfalls to obtain equivalent areal rainfalls. Areas (A) between 30 and 5,000 hectares based on Holland's formula $\Gamma\left(\frac{\sqrt{0.0009A}}{1-F}\right)=t$ where F= area factor, A= areas (hectares) and t= time (minutes)

Figure 2. Area factors (metric units)